

Supernova and GRB connection: Observations and Questions

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Abstract. We review the observational status of the supernova/gamma-ray burst connection. Present data suggest that SNe associated with GRBs form a heterogeneous class of objects including both bright and faint hypernovae and perhaps also ‘standard’ Ib/c events. Evidence for association with other types of core-collapse SNe (e.g. IIa) is much weaker. After combining the local GRB rate with the local SN-Ibc rate and beaming estimates, we find the ratio GRB/SNe-Ibc in the range $\sim 0.5\% - 4\%$. In most SN/GRB associations so far discovered, the SN and GRB events appear to go off simultaneously. In some cases data do not exclude that the SN explosion may have preceded the GRB by a few days. Finally we discuss a number of novel questions started by recent cases of GRB-SN associations.

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INTRODUCTION

Intensive optical, infrared and radio follow-up of GRBs, occurring in the last decade, has established that long-duration GRBs (Klebesadel 1990; Dezalay et al. 1992; Kouveliotou et al. 1993), or at least a significant fraction of them, are directly connected with supernova explosions. Most of the evidence arises from observations of supernova features in the spectra of a few GRB afterglows. Examples of the SN/GRB connection include SN 1998bw/GRB 980425 (Galama et al. 1998), SN 2003dh/GRB 030329 (Stanek et al. 2003, Hjorth et al. 2003), SN 2003lw/GRB 031203 (Malesani et al. 2004), SN 2002lt/GRB 021211 (Della Valle et al. 2003), XRF 020903 (Soderberg et al. 2005), SN 2005nc/GRB 050525A (Della Valle et al. 2006) and more recently SN 2006aj/GRB 060218 (Masetti et al. 2006; Modjaz et al. 2006, Campana et al. 2006; Sollerman et al. 2006; Pian et al. 2006; Mirabal et al. 2006; Cobb et al. 2006). In addition there are about a dozen afterglows which show, days to weeks after the gamma-ray events, rebrightenings and/or flattenings in their lightcurves (e.g. Zeh et al. 2004). These bumps are interpreted as SNe emerging out of their afterglows (Bloom et al. 1999, Castro-Tirado & Gorosabel 1999). The detection of star-formation features in the host galaxies of GRBs (Djorgovski et al. 1998, Fruchter et al. 1999) provided the earliest hint for the existence of a link between GRBs and the death of massive stars. Le Floc’h et al. (2003) and Christensen, Hjorth & Gorosabel (2004) have found that GRB hosts are galaxies with a fairly high (relative to the local Universe) star formation of the order of $10 M_{\odot} \text{ yr}^{-1} / L^{\star}$ or more, while recent studies on the parent galaxies of GRBs (Conselice et al. 2005, Wainwright et al. 2005) show that a significant fraction of GRB

hosts ($\sim 50\%$) exhibit a merger/disturbed morphology.

GRB 980425/SN 1998BW

SN 1998bw was the first SN discovered spatially and temporally coincident with a GRB (GRB 980425; Galama et al. 1998). It was discovered in the nearby galaxy ESO 184-G82 at 40 Mpc. This implied that GRB 980425 was underenergetic by about 3–4 orders of magnitude with respect to the “standard” γ -energy budget of $\sim 10^{51}$ erg (Frail et al. 2001, Panaitescu & Kumar 2001). The associated SN was extremely energetic with expansion velocities 3–4 times higher than those exhibited by normal Ib/c SNe (Patat et al. 2001). The theoretical modeling of the light curve and spectra (Iwamoto et al. 1998; Woosley, Eastman, & Schmidt 1999) suggests that SN 1998bw originated in a $\sim 40M_{\odot}$ star (on the main sequence), with a C+O core of about $\sim 10M_{\odot}$. This picture is supported by the radio properties of SN 1998bw (Kulkarni et al. 1998, Weiler et al. 2002) that can be explained in terms of an interaction of a mildly relativistic ($\Gamma \sim 1.8$) shock with a dense circumstellar medium fed by the strong wind of the massive envelope-stripped progenitor. Recently, Maeda et al. (2006), after analyzing the Fe and [O I] line profiles in the nebular spectra of SN 1998bw, give support to the idea that SN 1998bw was the product of an asymmetric explosion (see also Höflich, Wheeler & Wang 1999) viewed relatively off-axis from the jet direction, $\theta < 30^{\circ}$ (Maeda et al. 2006) and $\theta > 15^{\circ}$ (Yamazaki et al. 2003). An asymmetric explosion decreases the kinetic energy input by a factor $\lesssim 3$ (in Maeda et al. models) with respect to spherically symmetric models.

However, the association between two peculiar astrophysical objects, such as SN 1998bw and GRB 980425 was not taken as proof of a general SN/GRB connection.

GRB 021211/SN 2002LT

GRB 021211 was detected by the HETE-2 satellite (Crew et al. 2003), allowing the localization of its optical afterglow (Fox et al. 2003) and the measurement of its redshift $z = 1.006$ (Vreeswijk et al. 2006). Figure 1 shows the result of the late-time photometric follow-up, carried out with the ESO VLT-UT4 (Della Valle et al. 2003), together with observations collected from literature. A rebrightening is apparent, starting ~ 15 days after the burst and reaching the maximum ($R \sim 24.5$) during the first week of January. For comparison, the host galaxy has a magnitude $R = 25.22 \pm 0.10$, as measured in late-time images. The spectrum of the bump (Fig. 1, right panel) obtained during the rebrightening phase is characterized by a broad absorption, the minimum of which is measured at $\sim 3770 \text{ \AA}$ (in the rest frame of the GRB). The comparison with the spectra of other SNe supports the identification of the broad absorption with a blend of the Ca II H and K absorption lines. The blueshifts corresponding to the minimum of the absorption and to the edge of the blue wing imply velocities $v \sim 14400 \text{ km/s}$ and $v \sim 23000 \text{ km/s}$, respectively. In Fig. 1 the light curve of SN 1994I (dereddened by $A_V = 2 \text{ mag}$) is added to the afterglow and host contributions, after applying the appropriate K -correction (solid line). As it can be seen, this model reproduces well the shape of the observed light curve. It is interesting to note that SN 1994I (the spectrum of which provides the best match

to the observations) is a “standard” type-Ic event (Filippenko et al. 1995) rather than a bright *hypernova* (HN) (a hypernova is a broad-line type-Ibc SN) as the ones proposed for association with other long-duration GRBs. However we note that even if the pre-maximum spectra of some HNe (e.g. 2002ap, Mazzali et al. 2002) show significantly broader lines than our case, this difference vanished after maximum, such that it may not be easy to distinguish at later stages between the two types of SNe.

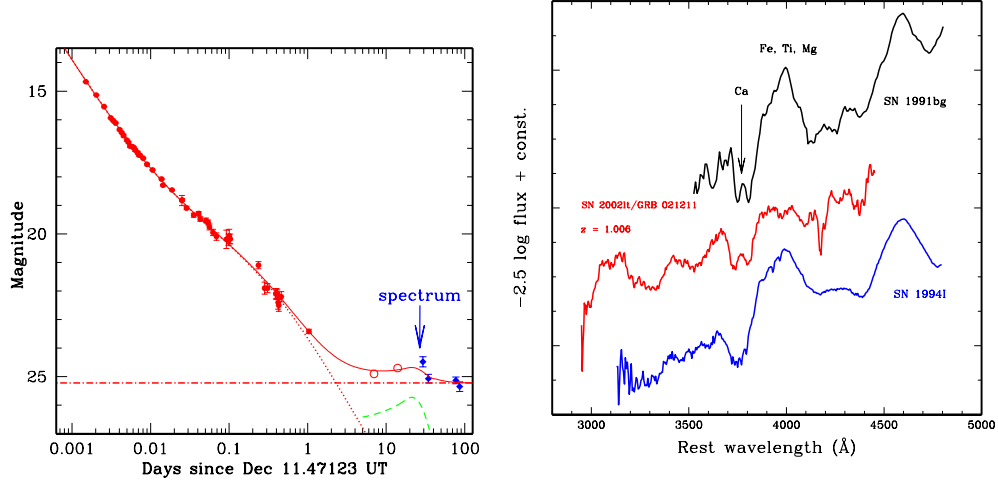


FIGURE 1. Left panel. Light curve of the afterglow of GRB 021211. Filled circles represent data from published works (Fox et al. 2003; Li et al. 2003; Pandey et al. 2003), open circles are converted from HST measurements (Fruchter et al. 2002), while filled diamonds indicate our data; the arrow shows the epoch of our spectroscopic measurement. The dotted and dot-dashed lines represent the afterglow and host contributions respectively. The dashed line shows the light curve of SN 1994I reported at $z = 1.006$ and dereddened with $A_V = 2$ (from Lee et al. 1995). The solid line shows the sum of the three contributions. **Right panel.** Spectrum of the afterglow+host galaxy of GRB 021211 (middle line), taken on 2003 Jan 8.27 UT (27 days after the burst). For comparison, the spectra of SN 1994I (type Ic, bottom) and SN 1991bg (peculiar type Ia, top) are displayed, both showing the Ca absorption. Plots from Della Valle et al. (2003, 2004).

THE “SMOKING GUN”: GRB 030329/SN 2003DH

The breakthrough in the study of the GRB/SN association arrived with the bright GRB 030329. This burst, also discovered by the HETE-2 satellite, was found at a redshift $z = 0.1685$ (Greiner et al. 2003). SN features were detected in the spectra of the afterglow by several groups (Stanek et al. 2003, Hjorth et al. 2003; see also Kawabata et al. 2003; Matheson et al. 2003a) and the associated SN (SN 2003dh) looked strikingly similar to SN 1998bw (Fig. 2). The gamma-ray and afterglow properties of this GRB were not unusual among GRBs, and therefore, the link between GRBs and SNe was eventually established to be general.

The modeling of the early spectra of SN 2003dh (Mazzali et al. 2003) has shown that SN 2003dh had a high explosion kinetic energy, $\sim 4 \times 10^{52}$ erg (if spherical symmetry is assumed). However, the light curve derived from fitting the spectra suggests that SN

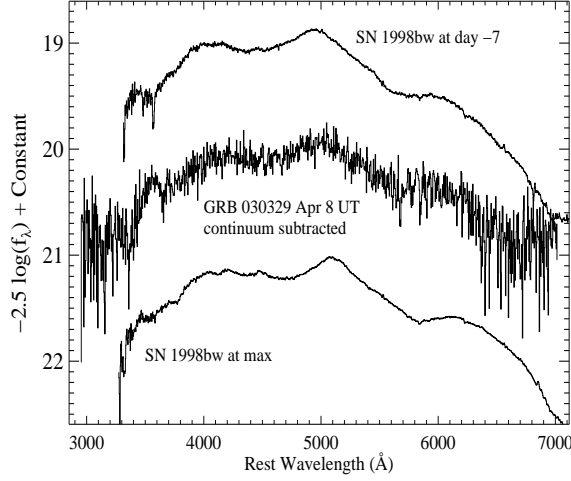


FIGURE 2. Spectrum of SN 2003dh taken on 2003 April 8, after subtracting the spectrum of April 4 rescaled. The residual spectrum shows broad bumps at approximately 5000 and 4200 Å (rest frame), which is similar to the spectrum of the peculiar type-Ic SN 1998bw a week before maximum light (Patat et al. 2001). Plot from Stanek et al. 2003.

2003dh was probably fainter than SN 1998bw (but see Bloom et al. 2004), ejecting only $\sim 0.35 M_{\odot}$ of ^{56}Ni . The progenitor was a massive envelope-stripped star of $\sim 35 - 40 M_{\odot}$ on the main sequence. The spectral analysis of the nebular-phase emission lines carried out by Kosugi et al. (2004) suggests that the explosion of the progenitor of GRB 030329 was aspherical, and that its axis was well aligned with both the GRB relativistic jet and our line of sight.

GRB 031203/SN 2003LW

GRB 031203 was a 30s burst detected by the INTEGRAL burst alert system (Mereghetti et al. 2003) on 2003 Dec 3. At $z = 0.1055$ (Prochaska et al. 2004), it was the second closest burst after GRB 980425. The burst energy was extremely low, of the order of 10^{49} erg, well below $\sim 10^{51}$ erg of normal GRBs. In this case, a very faint NIR afterglow was discovered, orders of magnitude dimmer than usual GRB afterglows (Malesani et al. 2004). A few days after the GRB, a rebrightening was apparent in all optical bands (Thomsen et al. 2004; Cobb et al. 2004; Gal-Yam et al. 2004). For comparison, in Fig. 3 the *VRI* light curves of SN 1998bw are plotted (solid lines), placed at $z = 0.1055$, stretched by 1.1 and dereddened with $E_{B-V} = 1.1$. After assuming a light curve shape similar to SN 1998bw, which had a rise time of 16 days in the *V* band, data suggest an explosion time nearly simultaneous with the GRB. With the assumed reddening, SN 2003lw appears to be brighter than SN 1998bw by 0.5 mag in the *V*, *R*, and *I* bands. The absolute magnitudes of SN 2003lw are hence $M_V = -19.75 \pm 0.15$, $M_R = -19.9 \pm 0.08$, and $M_I = -19.80 \pm 0.12$. Fig. 3 also shows the spectra of the rebrightening on 2003 Dec 20 and Dec 30 (14 and 23 rest-frame days after the

GRB), after subtracting the spectrum taken on Mar 1 (81 rest-frame days after the GRB, Tagliaferri et al. 2004). The spectra of SN 2003lw are remarkably similar to those of SN 1998bw obtained at comparable epochs (shown as dotted lines in Fig. 3). Both SNe show very broad absorption features, indicating high expansion velocities. The analysis of early spectra of 2003lw (Mazzali et al. 2006) indicates that this HN produced about $\sim 0.5M_{\odot}$ of Ni. The progenitor mass could be as large as 40-50 M_{\odot} on the main sequence.

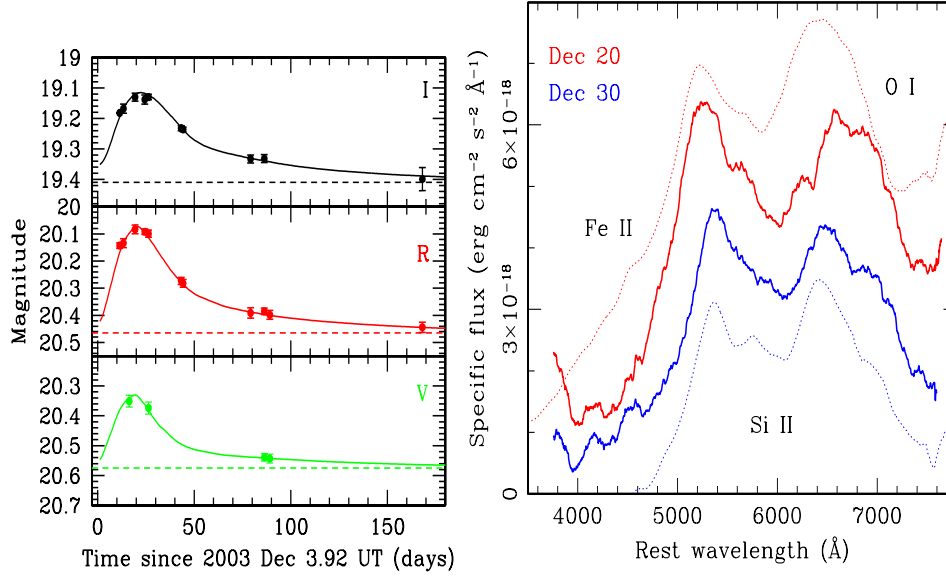


FIGURE 3. **Left panel.** Optical and NIR light curves of GRB 031203 (dots). The solid curves show the evolution of SN 1998bw (Galama et al. 1998; McKenzie & Schaefer 1999), rescaled at $z = 0.1055$, stretched by a factor 1.1, extinguished with $E(B - V) = 1.1$, and brightened by 0.5 mag. The dashed lines indicate the host galaxy contribution. **Right panel.** Spectra of SN 2003lw, taken on 2003 December 20 and 30 (solid lines), smoothed with a boxcar filter 250Å wide. Dotted lines show the spectra of SN 1998bw (from Patat et al. 2001), taken on 1998 May 9 and 19 (13.5 and 23.5 days after the GRB, or 2 days before and 7 days after the V-band maximum, respectively), extinguished with $E(B - V) = 1.1$ and a Galactic extinction law (Cardelli et al. 1989). The spectra of SN 1998bw were vertically displaced for presentation purposes. Plots from Malesani et al. 2004.

RATES OF SNE IB/C, HYPERNOVAE AND GRBS

GRB 980425, XRF 020903, GRB 031203, and GRB 060218 have γ -energy budgets between 2–4 orders of magnitude fainter than those exhibited by “standard” GRBs. The increasing number of discovery of these underenergetic events (with an associated SN component) can no longer be considered a simple collection of peculiar, atypical cases. These bursts were so faint, that they would have been easily missed at cosmological distances, therefore it is very possible that they are the most frequent GRBs in the universe. These 4 events have been detected in 9 years of observations within a volume of $\sim 4 \text{ Gpc}^3$ (XRF 020903 is the most far away under-energetic event so far observed,

TABLE 1. Hypernovae

SN	cz km/s	References
1997dq	958	Mazzali et al. 2004
1997ef	3539	Filippenko 1997b
1998bw	2550	Galama et al. 1998
1999as	36000	Hatano et al. 2001
2002ap	632	Mazzali et al. 2002, Foley et al. 2003
2002bl	4757	Filippenko et al. 2002
2003bg	1320	Filippenko & Chornack 2003
2003dh	46000	Stanek et al. 2003, Hjorth et al. 2003
2003jd	5635	Filippenko et al. 2003; Matheson et al. 2003b
2003lw	30000	Malesani et al. 2004
2004bu	5549	Foley et al. 2004
2005kz	8117	Filippenko, Foley & Matheson 2005
2006aj	9000	Masetti et al. 2006

at $z = 0.25$). These figures may imply an “observed” rate of $\sim 0.1 \text{ GRB Gpc}^{-3} \text{ yr}^{-1}$. On the other hand the “observed” rate has to be corrected to account for the effective full-sky coverage of the satellites. This task is not so simple to be carried out because the correction should include different factors (effective field of view, downtimes. . .) which are not easy to be quantify. As a conservative estimate (based on the published technical reports) one can crudely assume a correction factor of $\gtrsim 10$. Then the “observable” local rate turns out to be: $\sim 2 \text{ GRB Gpc}^{-3} \text{ yr}^{-1}$, which is slightly larger than derived by Schmidt (2001) ($\sim 0.5 \text{ GRB Gpc}^{-3} \text{ yr}^{-1}$) and consistent with $1.1 \text{ GRB Gpc}^{-3} \text{ yr}^{-1}$ derived by Guetta et al. (2004).

A rate of $\sim 2.6 \times 10^4 \text{ SNe-Ibc Gpc}^{-3} \text{ yr}^{-1}$ can be derived by combining the the local density of B -band luminosity of $\sim 1.2 \times 10^8 L_{B,\odot} \text{ Mpc}^{-3}$ (e.g. Madau, Della Valle & Panagia 1998) with the local rate of 0.22 SNe-Ibc (in Irr and Sm Hubble types) per century and per $10^{10} L_{B,\odot}$ (Cappellaro, Evans & Turatto 1999). This SN rate has to be compared with $\lesssim 2 \text{ GRB Gpc}^{-3} \text{ yr}^{-1}$ after rescaling for the jet beaming factor¹. There exist different estimates for this parameter: from ~ 500 (Frail et al. 2001) to ~ 75 (Guetta, Piran & Waxman 2005), corresponding to beaming angles $\sim 4^\circ$ – 10° , respectively. Taking these figures at their face value, we find the ratio GRB/SNe-Ibc to be in the range: $\sim 4\% - 0.5\%$. Izzard et al. (2004) have modeled the stellar progenitors of type-Ibc SNe, selecting those capable to produce GRBs. They find ratios comparable with the numbers presented here. Radio and optical surveys give less severe constraints: Soderberg et al. (2006b) and Rau et al. (2006) find $f_b^{-1} \lesssim 10^4$ and $f_b^{-1} \lesssim 12500$, then implying $\theta \gtrsim 0.8^\circ$ and GRB/SNe-Ibc $\lesssim 30\%$.

The computation of the ratio GRB/HN requires a further step. The measurement of the SN rate is based on the control-time methodology (Zwicky 1938) that implies the systematic monitoring of galaxies of known distances. Unfortunately all HNe so far discovered (see Tab. 1) have been not found during “time controlled” surveys. An

¹ The beaming factor is defined as $f_b^{-1} = 1 - \cos \theta$

TABLE 2. Supernova/gamma-ray burst time lag. A negative time lag indicates that the SN explosion precedes the GRB.

GRB	SN	+ Δt (days)	- Δt (days)	references
GRB 980425	1998bw	0.7	2	Iwamoto et al. 1998
GRB 000911	bump	1.5	7	Lazzati et al. 2001
GRB 011121	2001ke	0	5	Bloom et al. 2002b
		–	a few	Garnavich et al. 2003
GRB 021211	2002lt	1.5	3	Della Valle et al. 2003
GRB 030329	2003dh	2	8	Kawabata et al. 2003
		–	2	Matheson et al. 2003a
GRB 031203	2003lw	0	2	Malesani et al. 2004
GRB 041006	bump	2.7	0.9	Stanek et al. 2005
GRB 050525A	2005nc	0	< 3.5	Della Valle et al. 2006
GRB 060218	2006aj	0	0	Campana et al. 2006

heuristic approach to derive the rate of HNe is to compute the frequency of occurrence of all SNe-Ib/c and HNe in a limited distance sample of objects and to assume that they have been efficiently (or inefficiently) monitored by the same extent. From an upgraded version of Asiago catalog we have extracted 91 SNe-Ib/c (8 of which are HNe) with $cz < 6000$ km/s. This velocity threshold is suitable to make the distance distribution of ‘normal’ Ib/c and HNe statistically indistinguishable (KS probability=0.42). After excluding SN 1998bw, because it was searched in the error-box of GRB 980425, one can infer that the fraction of HNe is about $7/91 \simeq 8\%$ of the total number of SNe Ib/c. Therefore the ratio GRB/HNe turns out to be $\sim 0.5 \div 0.06$ (cfr. ~ 1 , Podsiadlowski et al. 2004).

Finally we like to stress two points: a) sub-energetic GRBs may be less collimated than classical events. Their low energy demand does not pose any problem for most progenitor models, thus the beaming factor does not need to be too large. Moreover, from the sparse data on their afterglows, it appears that their breaks are quite late, if existent. For example, interpreting the break in the X-ray light curve of GRB 031203 as due to a jet we obtain $\theta \sim 16^\circ \div 30^\circ$. Therefore it is likely that small GRB/SN ratios are favored; b) the estimate of the “local” rate of GRBs is seriously plagued by the small number of available events. For example, if we consider only the 3 nearest events (which have occurred within 0.4 Gpc^3) we cannot exclude values as high as $\sim 15 \text{ GRB Gpc}^{-3} \text{ yr}^{-1}$. In this case the ratio GRB/SNe-Ibc becomes $\sim 30\% - 4\%$ (for $f_b = 500$ and 75 , respectively). The former value would imply that a significant fraction of “standard” SNe-Ibc contributes to originate GRBs. The latter value might be consistent with a ratio GRB/HNe ~ 1 .

FACTS AND OPEN QUESTIONS

From the data presented in the previous sections, a number of both established facts and intriguing questions emerge:

1. Long duration GRBs are closely connected with the death of massive stars. This has been spectroscopically confirmed over a large range of redshifts:

GRB 980425/SN 1998bw at $z = 0.0085$ (Galama et al. 1998); GRB 060218/SN 2006aj at $z = 0.03$ (Campana et al. 2006); GRB 031203/SN 2003lw at $z = 0.1055$ (Malesani et al. 2003); GRB 030329/SN 2003dh at $z = 0.16$ (Stanek et al. 2003, Hjorth et al. 2003); XRF 020903/SN 1998bw-like at $z = 0.23$ (Soderberg et al. 2005); GRB 050525A/SN 2005cn at $z = 0.6$ (Della Valle et al. 2006); and GRB 021211/SN 2002lt at $z \sim 1$ (Della Valle et al. 2003). In spite of this tight connection with SN explosions, Fruchter et al. (2006) have demonstrated that GRBs and SNe do not occur in similar galactic environments, these authors argue that this unexpected behavior may be related to the low metallicity content observed in the GRB hosts.

2. It is not clear whether or not only HNe (i.e. broad-lines SNe-Ibc) are capable of producing GRBs or even “standard” Ib/c events. There is weak evidence that other type of core-collapse SNe, such as type IIn, can contribute to the SN population of GRBs (Germany et al. 2000; Turatto et al. 2000; Rigon et al. 2003). However, in a recent study, Valenti et al. (2005) (see also Bosnjak et al. 2006) were not able to corroborate, on statistical basis, the associations with core-collapse SNe different from SNe-Ibc. The best evidence for the case of an association between a type-IIn SN and a GRB has been provided by Garnavich et al. (2003), who found that the color evolution of the bump associated with GRB 011121 is consistent with the color evolution of an underlying SN (SN 2001ke) strongly interacting with a dense circumstellar gas due to the progenitor wind.

3. GRB-SN data (including the bumps: Della Valle et al. 2003, Fynbo et al. 2004, Levan et al. 2005, Masetti et al. 2003, Price et al. 2003, Soderberg et al. 2005, Gorosabel et al. 2005, Stanek et al. 2005, Soderberg et al. 2006a, Bersier et al. 2006) indicate that the magnitude at maximum of SNe associated with GRBs may span a range of about 5 magnitudes, which is similar to that exhibited by “standard” stripped-envelope stars (Richardson, Branch & Baron 2006). However all GRB-SNe which have so far been spectroscopically confirmed appear to belong to the bright tail of SNe-Ib/c population (all have $M_V \sim -18.5/-19$). If this is the effect of an observational bias (which favors the spectroscopic observations of bright SNe) operating on a small number of objects or it has a deeper physical meaning is not yet clear.

4. There are events, such as XRF 040701 (Soderberg et al. 2005), for which the SN has been unsuccessfully searched with HST, down to magnitude $M_V \sim -15.8/-13$ (according to different assumption on the host galaxy extinction). These observations may imply that some GRBs can be associated with very underluminous SNe-Ibc. On the other hand such very faint objects have never been observed (see Richardson, Branch & Baron 2006). However, it should be noticed that a few unusually faint core-collapse events (belonging to the type-II class, not the Ib/c!) have been already observed at magnitudes $M_V \sim -13/-14.5$ (Turatto et al. 1998; Pastorello et al. 2004). It would be possible that SNe-Ibc of comparable low luminosity do exist but they have not been observed just because they are rarer objects than type II (SNe-Ibc are about 15-30% of type II in late spirals/Irr, e.g. Mannucci et al. 2005).

5. Several authors have reported the detection of Fe and other metal lines in GRB X-ray afterglows (e.g. Piro et al. 1999). If valid (see Sako et al. 2005 for a critical view) these observations would have broad implications for both GRB emission models and would strongly link GRBs with SN explosions. For example, Butler et al. (2003) have reported the detection in a Chandra spectrum of emission lines whose intensity and

blueshift would imply that a supernova occurred > 2 months prior to the γ event. This kind of observations can be accommodated in the framework of the *supranova* model (Vietri & Stella 1998), where a SN is predicted to explode months or years before the γ burst. In Tab. 2 we have reported the estimates of the lags between the SN explosions and the associated GRBs, as measured by the authors of the papers. After taking these data at their face value, one can conclude that most SN and GRB events occur simultaneously, and only in some case the SN may have preceded the GRB by a few days (at the most). However we note that Swift has not detected X-ray lines in any afterglows so far observed.

6. Only a very small fraction of all massive stars are capable of producing GRBs. SNe-Ibc appear to be the natural candidates because they have already lost the Hydrogen envelope when the collapse of the core occurs, then allowing the ultra-relativistic jets to escape from the progenitor star. Nevertheless this fact does not seem to be sufficient. According to the current SN and GRB rates and $\langle f_b \rangle$ estimates, only $\lesssim 4\%$ of type-Ibc SNe are able to produce GRBs. This implies that GRB progenitors must have some other special characteristic other than being just massive stars. Recent studies have extensively discussed the role that stellar rotation (Woosley & Heger 2006; Yoon & Langer 2005; Fryer & Heger 2005), binarity (Podsiadlowski et al. 2004; Mirabel 2004; Tutukov & Cherepashchuk 2003; Smartt et al. 2002), asymmetry (Maeda et al. 2005) and metallicity (e.g. Fruchter et al. 2006) play in the GRB phenomenon.

7. The “optical” properties (i.e. luminosity at peak and expansion velocities) of the 4 closest SNe associated with GRBs vary by at most $\sim \pm 50\%$, while the γ -budget covers about 4 order of magnitudes. These facts may be interpreted in at least 2 different ways: a) we may have observed intrinsically similar phenomena under different angles. GRB 030329/SN 2003dh may be viewed almost pole-on, GRB 980425/SN 1998bw relatively off-axis ($15^\circ < \theta < 30^\circ$), while GRB 031203/SN 2003lw may lie in between (Ramirez-Ruiz et al. 2005). A consequence of this scenario is that the γ -properties are strongly dependent upon the angle ($\sim \theta^4$), whereas the optical properties are affected much less by changing the viewing angle up to $\Delta\theta \sim 30^\circ$; b) the recent event GRB 060218/SN 2006aj ($E_{\text{iso}} \sim 6 \times 10^{49}$ erg), may suggest a different interpretation. This GRB may be an example of intrinsically fainter event (Campana et al. 2006; Amati et al. 2006). This might indicate that there exists an intrinsic dispersion in the properties of the relativistic ejecta for SNe having similar optical properties (e.g. peak of luminosity, velocity of the ejecta). This fact is not unconceivable after keeping in mind that the observed relativistic energies at play in the GRB phenomenon, at least in the local universe ($z < 0.1$), appear to be just tiny fluctuations ($10^{-2/-4}$) of the kinetic energy involved in the ‘standard’ SNe-Ibc ($\sim 10^{51}$ erg) or HN explosions ($\sim 10^{52}$ erg).

8. As for AGN, it has been proposed (Lamb et al. 2005, see also Kouveliotou et al. 2004 and Dado et al. 2004) a unification scheme where GRBs, XRRs, XRFs and SNe-Ibc are the same phenomenon, but viewed at different angles. Given the rates of GRBs and type Ibc SNe discussed in the section 6, the unification scenario would work for $\langle f_b^{-1} \rangle \sim 30000$, which would correspond to beaming angles of $\sim 0.5^\circ$. On the other hand the measured f_b^{-1} factors are much smaller, likely in the range 75–500 (Guetta et al. 2005, Yonetoku et al. 2005; van Putten & Regimbau 2003, Frail et al. 2001) that corresponds to beaming angles of $\sim 10^\circ - 4^\circ$.

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